

**Title: Application of a meso-scale based ballistic fabric model to the development of advanced lightweight engine fan blade-out containment structure.**

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## ABSTRACT

Developing design methodologies based on experimentally validated predictive numerical simulation methods will enhance existing capabilities in predicting failure modes and structural design optimization for the high velocity impact problems. This paper is thus concerned with the setup of a methodology for modeling and simulation of the containment problem for the case of a real hybrid metallic/soft layered composite fan case structure. To realize this new design, a debris protection fan case composed of a basic metallic shell structure with a dry Kevlar wrap around it is considered. The fan blade is made of titanium alloy modeled by a Johnson-Cook elastoplastic material in ABAQUS, while the metallic structure of the fan case is made of aluminum alloy also modeled as an elastoplastic material. A multilayered Kevlar *woven dry fabric* structure is wrapped around the thin aluminum shell to form a soft hybrid fan case. A woven fabric *material model* developed in ABAQUS has been used. This material model can capture the ballistic response of multi-layer fabric panels and is implemented as a VUMAT subroutine in an equivalent smeared shell element corresponding to the representative volume element (RVE) for computational efficiency. The aim is to assess how this material model can be applied in a real industrial application.

## INTRODUCTION

Since the 70's, the numerical simulations of perforation and penetration of targets by projectiles are subjects of interest. One such interesting application is the design and analysis of efficient lightweight engine fan blade out containment system [2,10,14]. In fact, in case of such engine malfunction, engine debris poses a serious threat to aircrafts and their occupants. Conventional methods for protecting aircrafts and their passengers rely on the use of heavy structures to restrict debris from escaping the containment case. However for better energy and economy efficiency, the need to strengthen and lighten aircrafts without sacrificing on

improved safety requirements has pushed the aerospace industry to explore alternatives to existing metallic containment systems [7,10]. Hybrid fan case containment structure is a novel design in the aerospace industry which combines the resistance of the metallic structures with the light weightiness and energy absorption capability of the composite structures. Developing design methodologies based on experimentally validated predictive numerical simulation methods will thus enhance existing capabilities in predicting failure modes and structural design optimization for the high velocity impact problems [1,3].

This paper thus proposes a modeling methodology for the simulation of the containment problem for the case of realistic hybrid metallic/soft layered composite structure. The debris protection casing is composed of a basic metallic shell layer, made of aluminum, around which woven Kevlar dry fabric layers are wrapped. The fan blade is made of titanium. Both metallic parts use standard plasticity coupled with damage models available in ABAQUS. The dry Kevlar fabric wrap is modeled by a computationally efficient shell-based mesoscale mechanics unit-cell model, suitable for ballistic impact response of multi-layer fabric laminates and implemented in ABAQUS software via its VUMAT facility [9].

In order to simulate the impact between the blade debris and the hybrid fan case, a multistep analysis process is used. In the first step, one performs a preloading stage using an implicit analysis to generate stress and strain in the blades as well as the global velocity vector of the blade induced by the build-up of the cruise rotational velocity. In the second step one performs an explicit analysis to study the impact between the blade debris and the hybrid fan case using results from the previous step. Some of the main issues considered in assessing the suitability of a computational model in industrial environment include finding a constitutive law capable of capturing the complex physical interaction including intra and inter layers failure mechanisms as well as contact interaction related to the gap size between the adjacent layers, and finding the appropriate mesh size limited by available computer capacity and production time [11,12]. A parametric study is then performed for assessing how this material model can be applied to an industrial problem and to further evaluate if our predictions in terms of the number of plies needed to contain the debris and total weight reduction are in agreement with industry observations.

The analysis comprises two separate sub-models: (i) a pre-stress model for initialization of field variables induced by setting up the motion of the fan blade from rest to cruise rotating speed; (ii) the model for blade debris release and its impact with the engine casing. The modeling technique is thus interesting in the sense that we use a first model to pre-constrain the fan blade following the rotating motion built-up and then use the accumulated deformation history to start the subsequent impact analysis. The setup of these two models is dealt with using specific tools and functionalities of Abaqus. The first analysis is solely concerned with the fan blade and is used to obtain the initial stresses and strains appearing in each element as well as the velocities of each node of the fan blade model when it is put in rotational motion. In Abaqus, this motion is defined by specifying an axis of rotation and a rotational velocity as well as multipoint constraints (MPCs). This analysis step is performed using Abaqus implicit solver, i.e. Abaqus standard. The results of this analysis are then imported in the subsequent analysis which deals with the impact of the fan blade debris on the engine casing. In this second analysis

phase, a new part, called engine casing, is created and assembled with the previous fan blade model. A hybrid engine casing is modeled using an aluminum cylindrical shell as the base structure defining the casing shape around which a dry fabric composite material is wrapped. For high velocity impact modeling involved in this containment simulation, the Abaqus explicit solver is used together with the developed VUMAT [9].

## DEVELOPMENT AND VALIDATION OF BALLISTIC FABRIC MODEL

In this paper a simplified engine fan blade containment problem is considered as an application of the work presented in ref [3]. All parameters and model geometry used in the paper are taken from our previous work [3,8] done using Ls-Dyna environment in order to validate our modeling results in ABAQUS environment. The first step in the design of hybrid lightweight fan case is to setup a valid constitutive model for the Kevlar wrap. A material model developed in [9] has been validated through a series of transient nonlinear dynamic analyses of the impact of a square-shaped fabric plate with a blunt projectile. The computed results in terms of projectile velocity throughout the analysis were compared to available experimental data (ELVS data). Figure 1 shows that the developed material model provides a reasonably good description for the fabric deformation and fracture behavior.

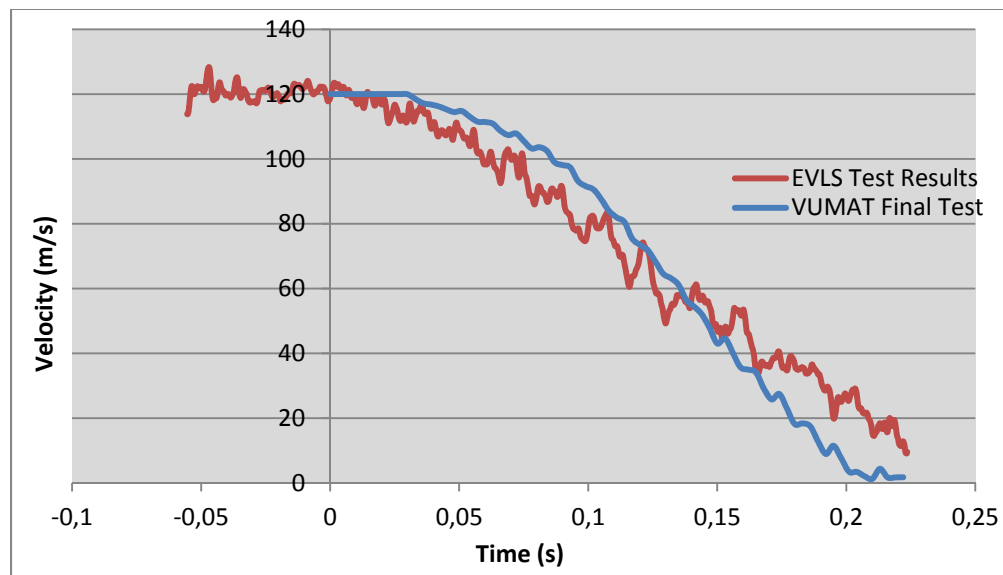


Figure 1: Comparison between FEM and experimental analyses from Shahkarami[7] of the impact velocity

## METHODOLOGY FOR THE NUMERICAL SIMULATION OF A FAN BLADE CONTAINMENT PROBLEM

In this section, details regarding the modeling methodology of the first and second sub-models for the fan blade impact analysis are presented. Then the results regarding the velocity of the blade during the impact are presented followed by a

discussion about the validity of the simulation results presented through the use of the energy evolution curves from the model.

### Implicit analysis: Stress Induced in the Blades by the Rotation

The first step of the simulation methodology is to generate the stress and strain built up in the blades by rotating the engine from rest up to a certain cruising rotational speed, set in our application to 1047rad/s. To perform this pre-stress analysis, an implicit dynamic finite element solver is required and we used the ABAQUS Standard solver, which implement the implicit algorithms for transient dynamic structural problems involving high velocity loadings. The generation of the model data involves the creation of the blades geometry and the assignment of material properties to the parts.

The objective of the first analysis is to obtain the pre-stresses distribution in the blade elements and the velocities at the nodes of the damaged fan blade induced by setting up the blade rotating motion from rest to cruise speed. To simplify the problem, an overall simplified geometry of the fan blade similar to the one used in [1,3] while working with LS-Dyna has been defined. However the geometry was slightly modified, since instead of using (see figure 8.2) four fan blades, only one blade is used here as in spin-test. Also the blade configuration proposed in [1,3] was modified so as to have a curved outer edge instead of a straight line. These modifications were required in order to obtain good convergence of the contact algorithm, to avoid high concentration of stresses and strains at one of the sharp outer edges of the blade and to reduce the computational time during these preliminary impact computations.

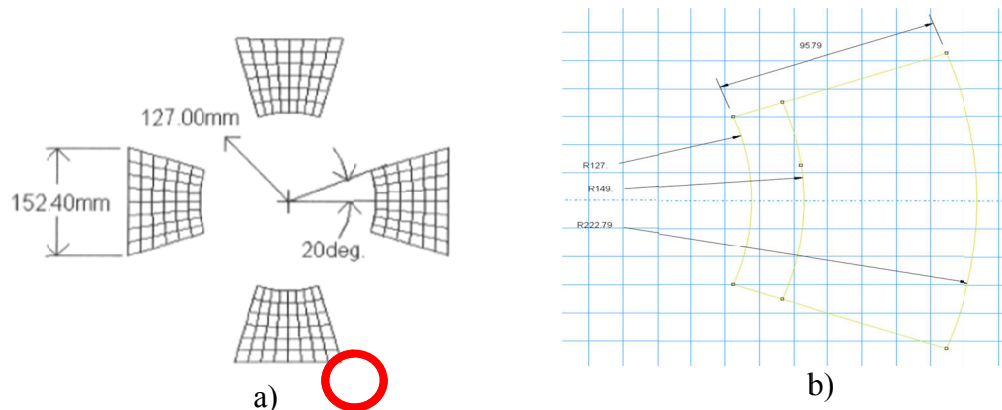


Figure 2: a) Fan blade geometry used in [42 GT]; b) fan blade geometry defined in Abaqus for the present work

### DEFINING THE GEOMETRY AND THE MATERIAL OF THE FAN BLADE

Figure 2 indicate that the fan blade is modeled using two distinct features or parts and this is done in order to easily introduce a crack in the second analysis step where the fan blade is broken into two parts: one that remains attached to the rotating shaft and the other that is ejected outward as a debris that impact the casing. The thickness of the blade shell elements is 4.98mm and the material

properties input in Abaqus are the same as those used in LS-Dyna by [3] to model the behaviour of the blade and are given in Table 1. The material chosen is titanium and the properties used are:  $\rho=0.004424 \text{ g/mm}^3$ ;  $E=115.142\text{GPa}$ ;  $\nu=0.35$ ;  $\sigma_Y=827.371\text{MPa}$ ;  $ETAN=951.476\text{MPa}$ ;  $FS=0.25$ .

|                       | Titanium     | Aluminium |
|-----------------------|--------------|-----------|
| Young's Modulus       | 115.1424 Gpa | 72 Gpa    |
| Poisson's Ratio       | 0.35         | 0.32      |
| Plastic: yield stress | 0.8273709    | 0.21378   |
| Plastic strain        | 0            | 0         |
| Plastic: ETAN         | 0.951476     | 0.077951  |
| Plastic strain        |              | 0.18      |
| Mass density          | 4.424        | 2.78      |
| Fracture Strain       | 0.25         | 0.18      |
| Stress Triaxiality    | 0.3          | 0.3       |
| Strain Rate           | 10           | 0         |

Table 1: Titanium properties for the definition of the fan blade and aluminium properties used for the engine casing

#### CONSTRAINING THE MODEL AND BOUNDARY CONDITIONS

In order to perform a flexible multibody analysis for rotating parts, two kinds of coupling are used in ABAQUS [9]. First, the base of the blade is attached to the control point at which we apply the boundary conditions to define the rotational motion as in figure 3. The other coupling is used to attach the two parts of the fan blade that we presented before and this is done by using the tie constraint available in Abaqus (as it is able to rigidly connect two sets of nodes very close to each other). Also a kinematic coupling constraint has to be defined between the reference point and the nodes at the base of the blade where the junction between the blade and the rotating shaft is located, in order to transmit the radial velocity applied to the reference point to the fan blade. The junction between the two parts is shown in Figure 3.

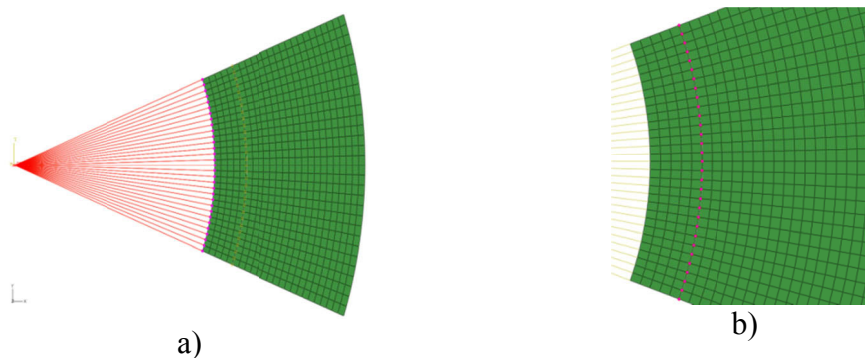


Figure 3: a) Coupling constraint between the control point and the base of the fan blade. b) Tie constraint between the two sub-components of the fan blade.

To set the rotating motion, we applied a velocity boundary condition to the reference point. Then assuming that the Z axis is the axis of rotation, we set the



value of the angular radial velocity to 1047 radians per second. Other angular velocities are set to zero. The velocity boundary condition is applied through the definition of amplitude which helps to apply the boundary condition in a very progressive manner so that we would not distort any element or cause any unnecessary strain or stress on the fan blade structure during the first seconds of the motion. Figure 4 gives the shape of the used amplitude corresponding to a smooth step time. It was noted that a non-smooth step time amplitude resulted in the immediate application of the full angular speed to an initially motionless system which translated into the application of an infinite acceleration to the blade base nodes that distorted the mesh and caused the analysis to crash. This smooth step time has been applied over 9 seconds meaning that the engine rotating speed goes from 0 to 1047 radians per second in that period of time.

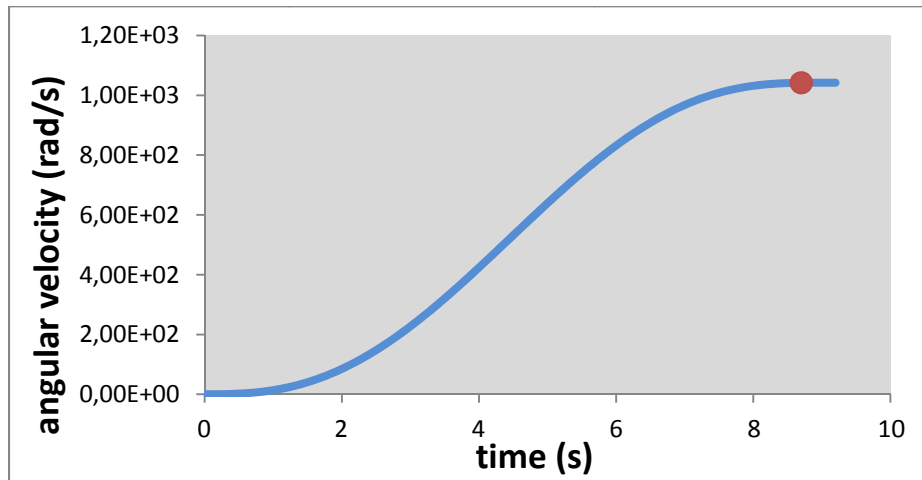


Figure 4: Progressive application of the rotating motion to the fan blade

Hence the velocities that are fed to the next analysis phase are extracted at time equal to 9 seconds as it is marked by a red dot in Figure 4. This is a critical point in time at which the stresses in the blade reach a maximum just before the establishment of a permanent regime.

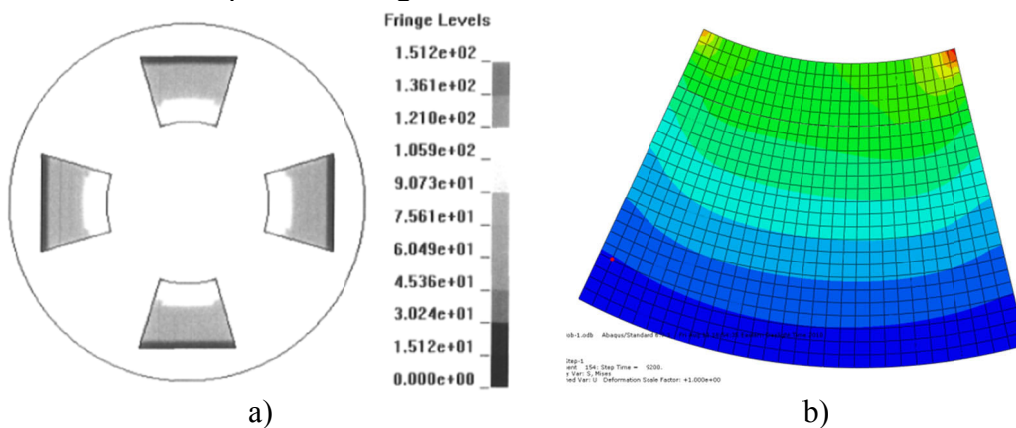


Figure 5: a) Stress distribution inside the fan blade obtained in [3] using LS-Dyna.  
b) Stress distribution obtained in Abaqus

Figure 5 shows the obtained stress distribution inside the fan blade at the end of the implicit analysis this is similar those obtained in [3] using in LS-DYNA (give a clearer picture assessing the two stress distributions). The velocity vector at each node of the fan blade will exported to the second analysis and this information will enable us to apply a velocity boundary condition in the impact analysis that will set the blade in motion in the explicit analysis.

### **Explicit analysis: Debris Generation and Impact on the Fan Case**

In this analysis phase, we have to simulate the blade release event (generation of debris) and to model and analyse the high velocity debris impact on the fan case. The material model for the blade is the same as the one presented in the previous section. The fan case is composed of two sections: the metallic ring part, to be impacted first and the dry Kevlar multiple layers woven fabric wrapped around it [1, 3]. We assigned a different material model to each of them. The metallic ring structure in Aluminium (Al) is modeled with the material properties with isotropic hardening given in table 1 and the Kevlar fabric wrap is modeled with a new advanced material model, the Fabric Crossover VUMAT model implemented in ABAQUS-Explicit [9]. A continuum modelling approach is used to model the fabrics in such a way that the interaction of yarns in a unit cell is smeared into a single representative S4R ABAQUS finite strain shell element.

The second analysis is performed using the Abaqus explicit solver. The fan blade geometry needs to be imported from the first analysis.odb result file. Also, on that geometry a velocity predefined field calling the previous .odb result file needs to be defined to set the fan blade in motion. The standard metallic engine casing is replaced by a hybrid model, meaning that it is made of an assembly of a metallic base layer and of several dry fabric composite layers wrapped around it. The Al material parameters are:  $\rho=0.0027\text{g/mm}^3$ ;  $E=68.948\text{GPa}$ ;  $\nu=0.33$ ;  $\sigma_Y=213.78\text{MPa}$ ;  $ETAN=77.951\text{MPa}$ ;  $FS=0.18$  and the values for the time vs strain rate are 1:1; 100:1.1; 1000:1.3; 2500:1.5. (Kevlar material is given in [3]). In the considered model there are four layers of Kevlar fabric wrapped around the cylindrical inner aluminum shell.

### **DEFINING THE GEOMETRY**

The first operation to set up the 2nd analysis is to create the geometric model of the engine casing. Then, from the implicit analysis result file, the geometry of the tip of the blade is imported and assembled to form the fan case model. The engine casing is thus made of four concentric cylinders. The innermost cylinder is metallic and the four other cylinders are made of fabric composite materials. Of course we will be using the developed VUMAT to model the composite behavior during impact. Each cylinder radius is increased by 0,2499mm to account for the exact thickness of the material. The inner radius of the innermost metallic skin is 250mm; the length of the cylinder is 150mm. These are approximately the values used in LS-Dyna by [1,3] which are respectively 249mm and 105mm.

## CONTACT INTERACTIONS, BOUNDARY CONDITIONS AND PREDEFINED FIELDS

To define the contact between the blade and each layer of material defining the casing as well as the contact between layers themselves, a “general contact” option

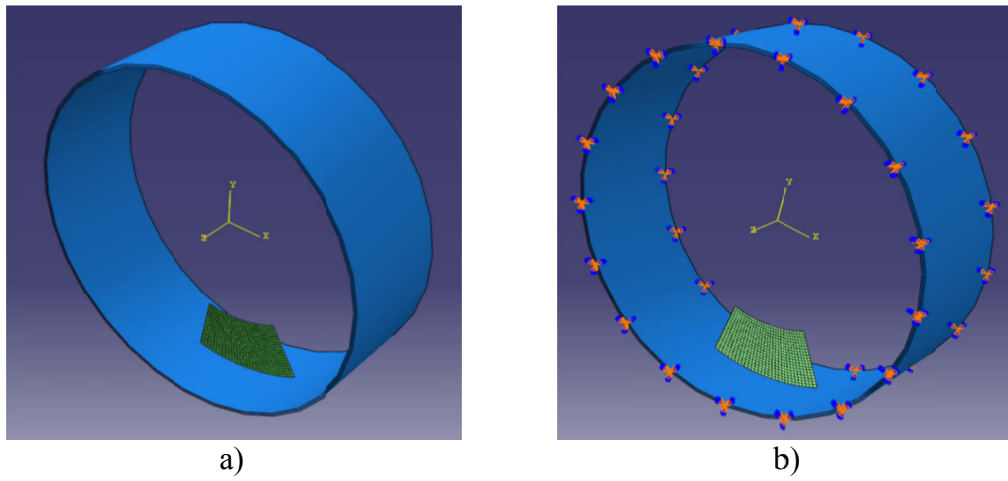


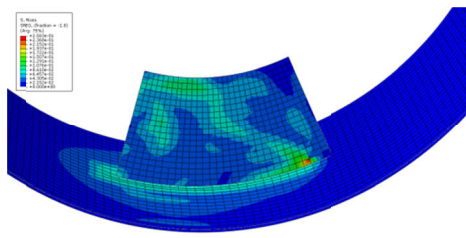
Figure 6: a) Assembly of the casing and the fan blade for the explicit analysis, b) definition of the boundary condition on the edges of the casing to fix it rigidly in space.

available in Abaqus was used and contact properties were used to define the mechanical surface interaction models that govern the behavior of surfaces when they are in contact. The default contact property model in Abaqus/Explicit assumes “hard” contact in the normal direction. Contact property assignments propagate through all analysis steps in which the general contact interaction is active. The normal behavior is set to allow separation after contact with a “Hard” contact pressure overclosure behavior using the standard constraint enforcement method. Tangential behavior is defined to be frictionless.

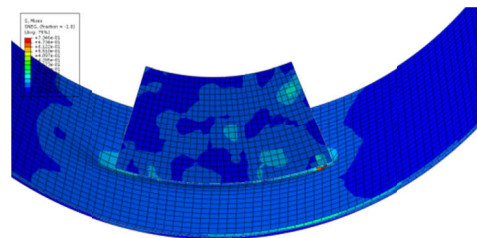
There is only one boundary condition applied to fix the casing in all directions of space as is shown in the previous picture (Figure 6). It has been applied at the two edges of the cylinders to approximate the manner in which the composite strap is integrated in the engine. The predefined fields consisting of velocities at each node of the blade as well as strains and stresses obtained at the end of the first analysis phase correspond to results extracted at the last frame that are imported and applied to the imported geometry of the blade.

## IMPACT RESULTS ON THE HYBRID CASING WITH A FOUR FABRIC LAYERS

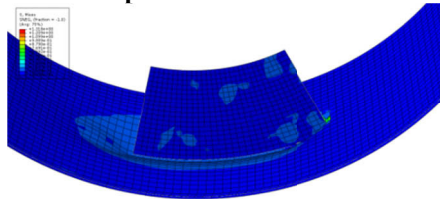
Figure 7 gives the graphical results showing the evolution of the blade impact analysis on the hybrid fancase. As it can be seen the blade is progressively penetrating the casing. The element deletion parameter is removing all the damaged elements from the analysis. The analysis takes approximately 20 minutes to run but this time could be reduced by modeling only half of the casing.



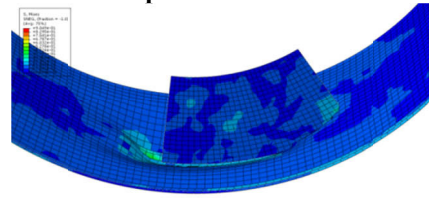
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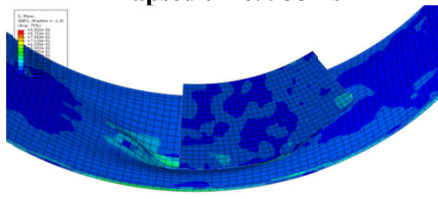
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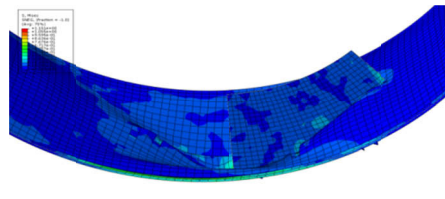
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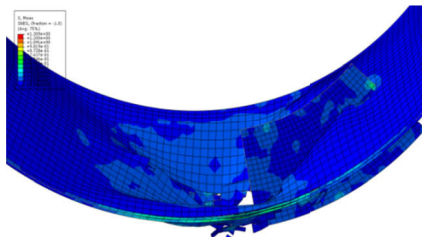
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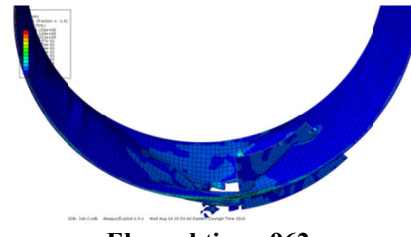
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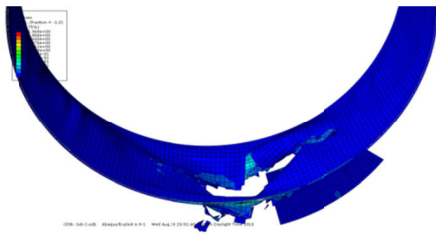
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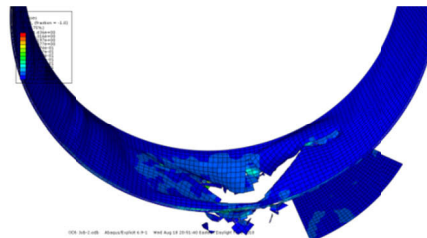
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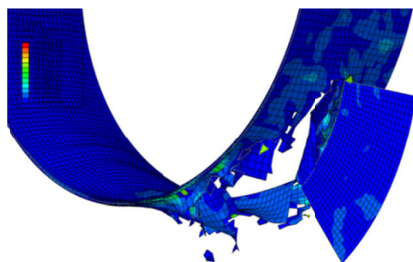
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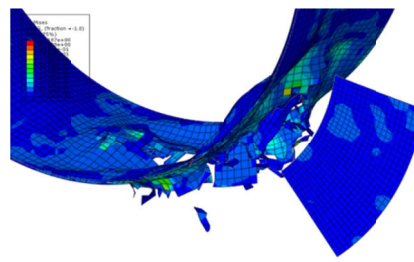
**Elapsed time: 967ms**



**Elapsed time: 967ms**



**Elapsed time: 972ms-view1**



**Elapsed time: 972ms-view2**

Figure 7: Graphical evolution of the impact analysis of the fan blade on the hybrid casing

In this configuration, the blade perforates the containment casing and exits at 125 m/s. Figure 8 shows the velocity drop of the fan blade during the impact. Also one note that the second dynamic analysis is starting at the point in time where the previous analysis stopped and this is why the curve is plotted from 9.2s .

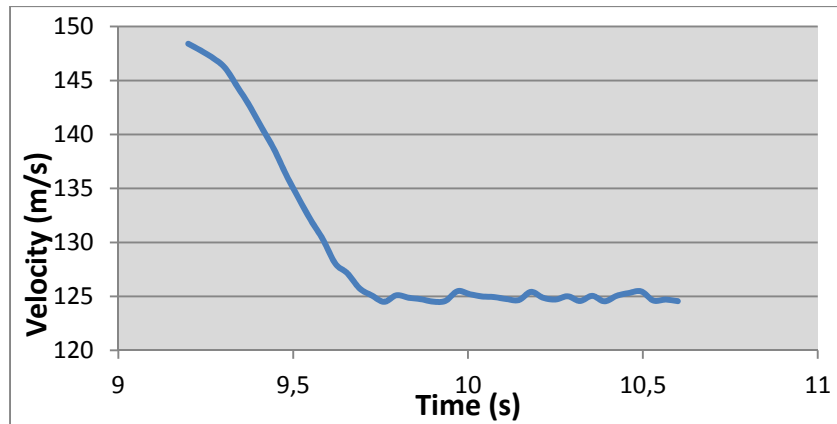


Figure 8: Curve of the blade's velocity over the duration of the analysis

Figure 9 shows the plot of the energy curves for the internal energy (ALLIE), the kinetic energy (ALLKE) and the total energy of the model (ETOTAL) during this impact analysis.

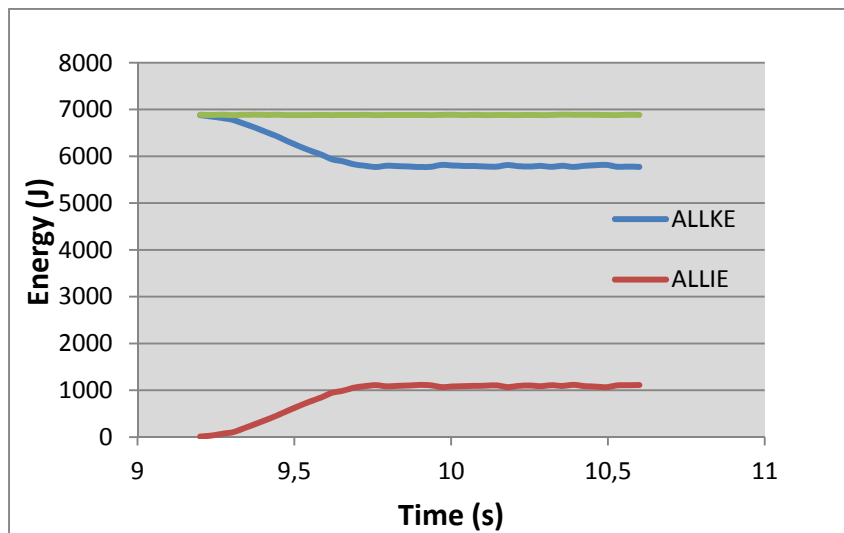


Figure 9: Energy curve of the blade's velocity over the duration of the analysis

We may observe that the total energy of the model remains constant over the duration of the analysis indicating that the model is consistent. Furthermore the observed loss of velocity is translated in a loss of kinetic energy which is transferred to the casing as internal strain energy that deforms and damages it. This is the main reason for the observed increase of internal energy of the model. Those few observations demonstrate that the model is behaving correctly.

## HYBRID FAN CASE CONTAINMENT STUDY

### Debris protection using multilayered dry fabric pate structure

In Figure we show a simple study on the impact of the projectile on a plate made of increasing number of fabric layer. This study was carried out to find out if the developed VUMAT can be used in predicting the number of fabric layers needed to prevent penetration of the blunt projectile impacting flat plate configuration. Since a shell element corresponding to the crossover model is used the computation time needed to obtain result increases drastically with the number of layers. First the final velocities after impact on a 1-ply plate, a 2-ply plate and a 4-ply plate were collected. All other parameters such as initial velocity, crimp angle of the fabric and element size remained the same for all analysis. In the case of the 1-ply impact, the final velocity of the impactor is 82m/s. In the case of the 2-ply plate, it is 58m/s and in the case of the 4-ply impact the final velocity is 18m/s. Also an analysis run with a 6-ply plate was performed and it was found out that this configuration completely stopped the projectile, as shown in figure 10.

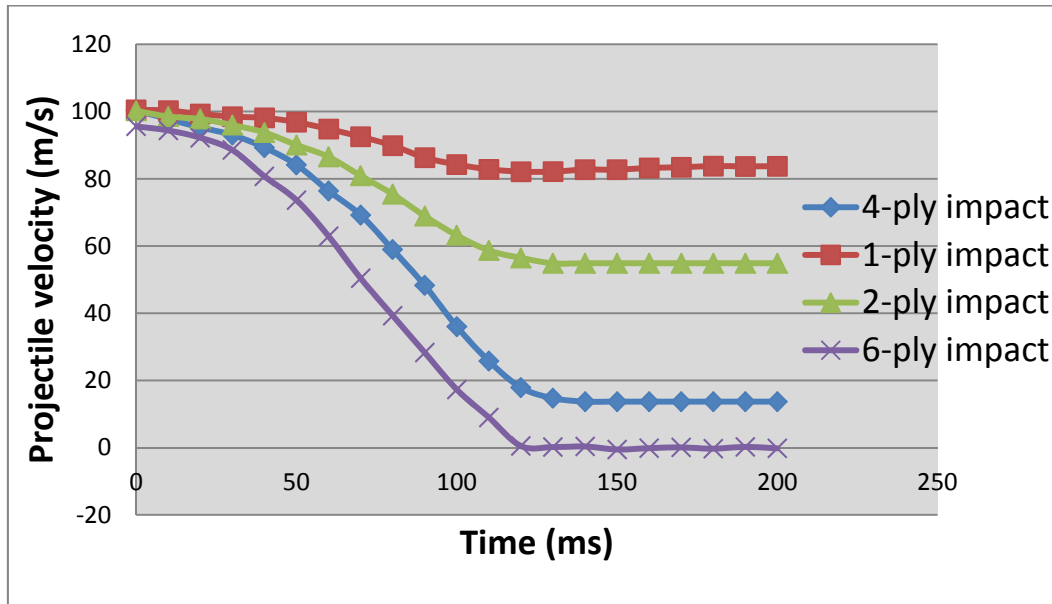


Figure 10: Influence of the number of layers over the final velocity of the projectile

### SIMPLIFIED FORMULA TO PREDICT NON-PENETRATION

Plotting each final velocity for 1-ply, 2-ply and 4-ply impacts, it is possible to create an analytic relation that could be used for prediction the numbers of layers required to prevent penetration. Using the three results a quadratic function was determined using Excel interpolation/extrapolation capabilities and this is presented in Figure . The quadratic function has the following equation where X is the number of layers:

$$f(X) = 2.7639X^2 - 37.161X + 118.12 \quad (1)$$

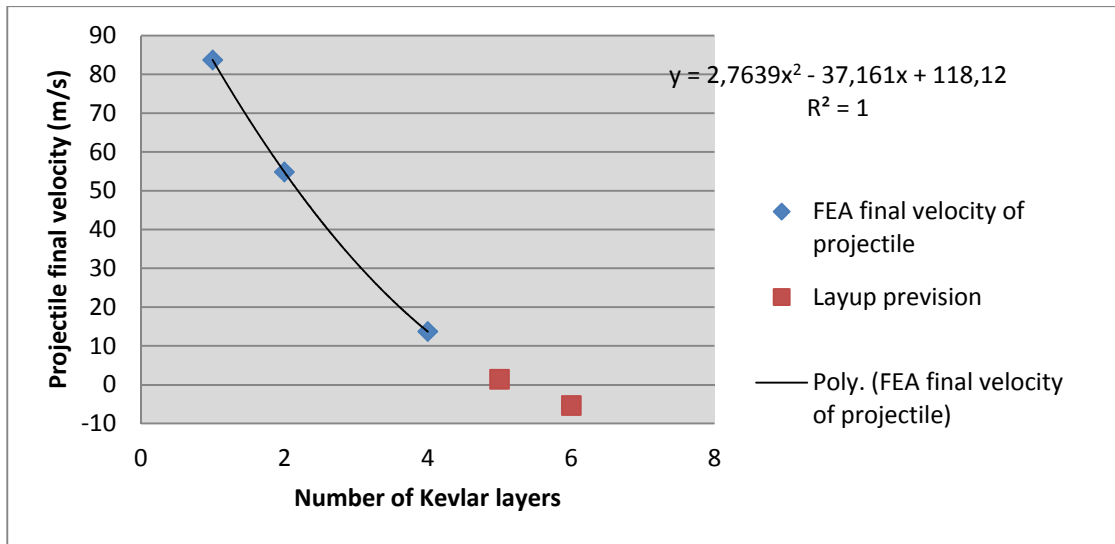


Figure 11: Prediction analysis to define the number of layers needed to stop the projectile

Using this equation, it was possible to predict the number of layers needed to stop the projectile. The projections for 5 and 6 layers of fabric are shown in figure 11 in red. We can observe that 5 layers are not enough to stop the projectile as the projected final velocity is 3m/s. The correct number of layers is seen to be 6 and it is interesting to note at this point that this is the result we get from Abaqus as it was mentioned previously.

Consequently we can conclude that for this simple impact test our predicting model based on equation 1 linking the final velocity of the impactor with the number of fabric layers is correct. This approach will be applied in an attempt to predict the number of layers in the hybrid fan casing needed to prevent escape of the fan blade debris.

### Impact on full metal casing

The analytic approach developed previously is here applied for the case of metallic structure in an attempt to finding the number of aluminum layers required to contain the fan blade debris. This has been done through a numerical trial and error approach. We set up 6 analyses to test different configurations of the engine containment involving different number of 0.5mm thick aluminum layers which is exactly the value used in[3] to set up the analysis in LS-Dyna. The configuration of the analysis is presented in figure 12 and depicts the 24-layer thick aluminum casing. The total computation time to run a 24-layer fully metallic model is approximately 35 minutes on standard dual core PC.

We tested the following configurations: 4 layers, 8 layers, 12 layers, 18 layers, 20 layers and 24 layers and extracted the final velocity of the projectile; the results are summarized in Table 2. This table shows that 24 layers are very close to stopping the projectile thus we can conclude that 25 layers of aluminum will definitely stop the projectile from escaping the containment but this has to be verified a posteriori.



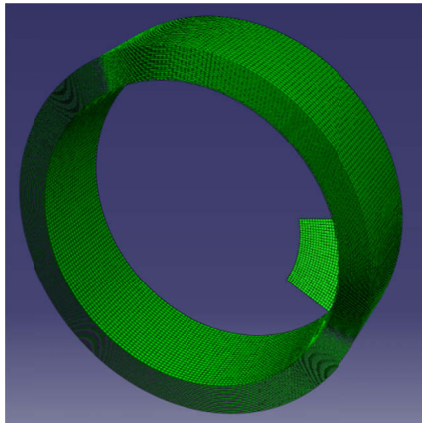


Figure 12: Fan containment made of 24 layers of aluminum

| Number of layers | Total thickness of the casing (mm) | Final velocity of the fan blade debris (m/s) |
|------------------|------------------------------------|--|
| 4                | 2                                  | 123,254                                      |
| 8                | 4                                  | 110,956                                      |
| 12               | 6                                  | 95,4771                                      |
| 18               | 9                                  | 81,8509                                      |
| 20               | 10                                 | 35,9109                                      |
| 24               | 12                                 | 0,6278                                       |

Table 2: Results obtained from FEA

The result shown in Figure 12 and in table 2 is interesting since it is very close to the result obtained by [3] through the FEA model where a thickness of 12.7mm of aluminum was enough to stop the debris. In our case, using a multilayered approach, stopping the blade requires about 25 layers of 0.5mm thickness which corresponds to a total thickness of 12.5mm. Obviously a unique 12.5mm thick layer could have been used to accomplish this task but doing it this way, our goal was to validate the adequacy of the contact algorithm used to model the interaction between numerous layers. Finally to fully verify our statement, we ran the analysis using 25 layers of aluminum and it is indeed stopping the blade as is shown in Figure 1. The stresses are very low at the end of the analysis because there is no longer any displacement of the blade and this is shown in figure Figure 1 b.



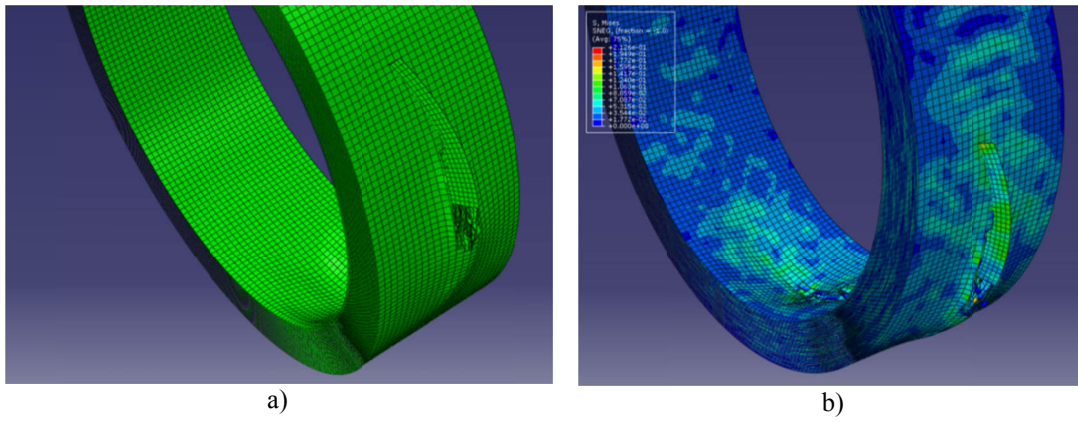


Figure 1: Analysis results for the 25-layer fan containment; a) the blade has been stopped inside the containment, b) graphical representation of the stresses at the end of the analysis.

Finally the FEA results were plotted in a graph to fully understand how a variation in the number of layers was affecting the final debris velocity. This is shown in figure 14 along with a quadratic regression of the results obtained through FEA modeling.

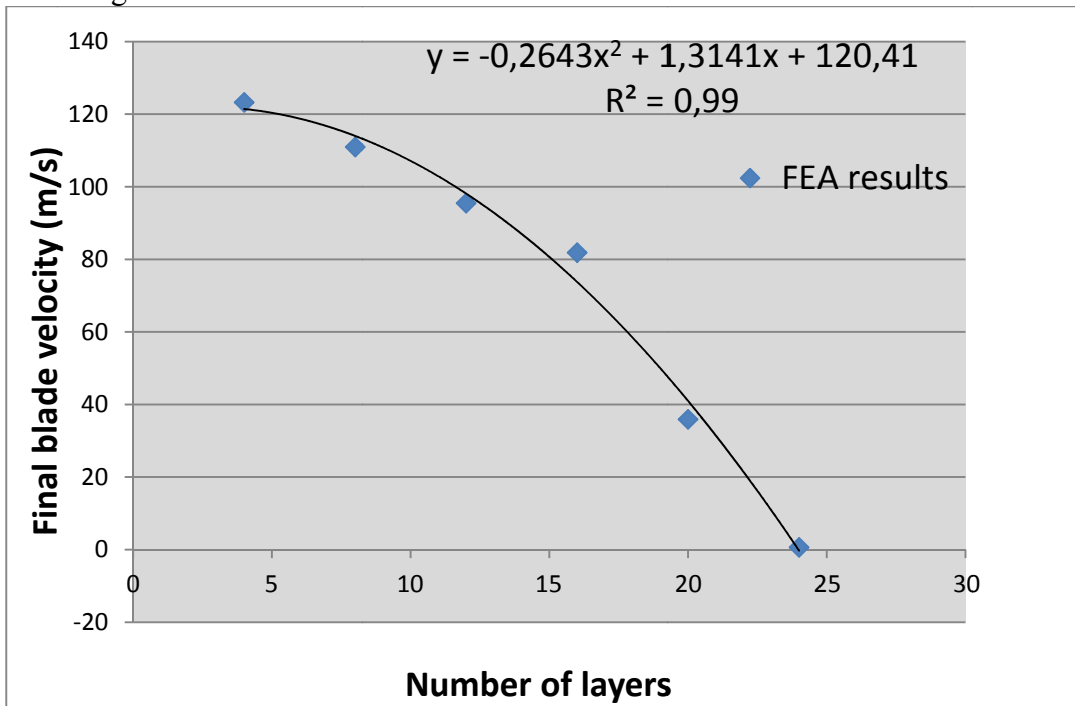


Figure 14: Curve of the blade's velocity over the duration of the analysis

The equation linking the number of layers in the containment with the final velocity of the blade is given as:

$$f(X) = -0.2643X^2 + 1.3141X + 120.41 \quad (2)$$

## Application to hybrid fan case

The preceding analysis for metallic structure is extended to hybrid fan case in order to find the number of fabric plies wrapped around an inner metallic casing required to contain the fan debris. As it was done before, we will correlate the number of layers of fabric with the final velocity of the blade. Simulations for 4, 6, 8 and 10 layers of fabric were run successfully and the obtained results are presented in Figure . The final velocity of the blade for the 4-ply casing is approximately 133m/s, for the 6-ply casing it is 131m/s, for the 8-ply casing it is 129m/s and finally for the 10-ply casing it is 124 m/s.

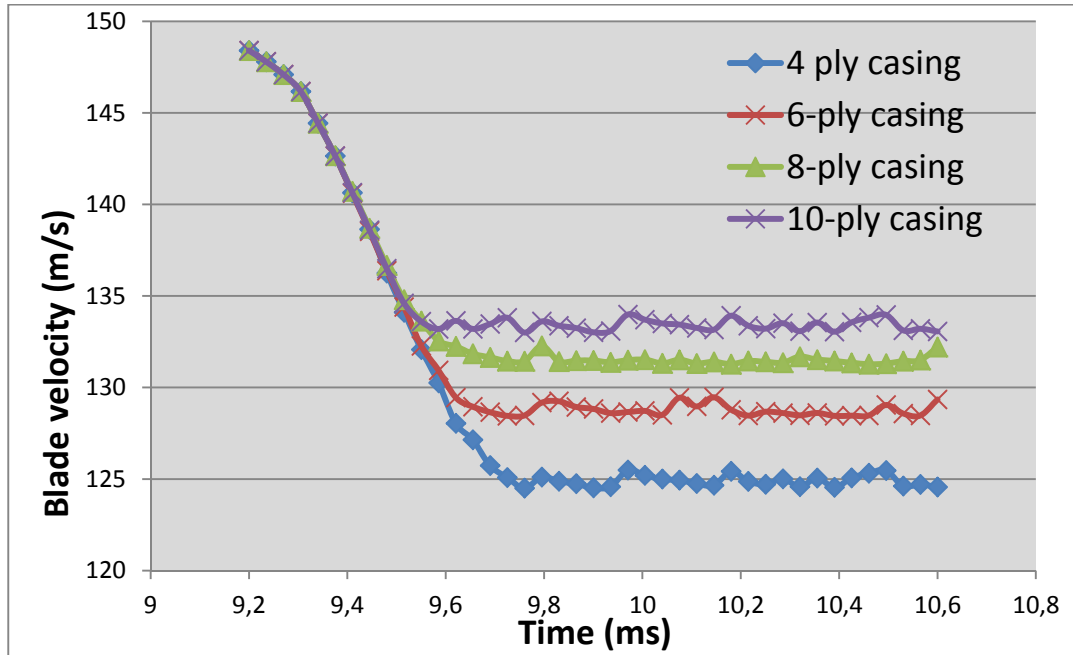


Figure 15: The fan blade's velocity evolution or different configurations of the hybrid casing

Several numerical tests were performed on multiple configurations of the hybrid casing with more than 10 layers of fabric on top of the metallic internal casing and the computational process was observed to become progressively unstable and terminated by numerical crashing. The phenomenon was observed to start at 11 layers of fabric. At this time, two explanations can be attempted. First, the lack of progressive damage model in the developed VUMAT has been identified as a potential problem which would lead to numerical instabilities. In our case, using the element deletion option in Abaqus implies that the element is removed as soon as the damage criterion is met and this may leads to a premature loss of material implying a loss of internal energy while affecting the stability and accuracy of the contact algorithm. Hence progressive damage and strain rate dependency should be implemented as a way to cure this problem. Also as described by Badel et al[13], another possibility to address the observed numerical instabilities would be to use a corotational frame based on fiber frame (FF approach) to update the material stress-strain history instead of the Green-Naghdi (GN) approach used here to produce the results. According to the later work, a calculation run using the FF approach

completed successfully in case of strongly anisotropic material whereas the GN based approach failed because this is more suited to initially isotropic materials with weak induced anisotropy. More developments thus need to be done to implement the FF approach in the VUMAT.

Despite the above mentioned VUMAT deficiencies, the four numerical results were however used to construct an extrapolated quadratic function (Figure ) in effort to try to predict the number of layers required to contain the debris. One can observe that the form of the equation (eqn 3) and its coefficient are very close to the one obtained for the fully metallic casing (eqn 2). It is not surprising that adding layers to the containment affects the final velocity of the debris in the similar way.

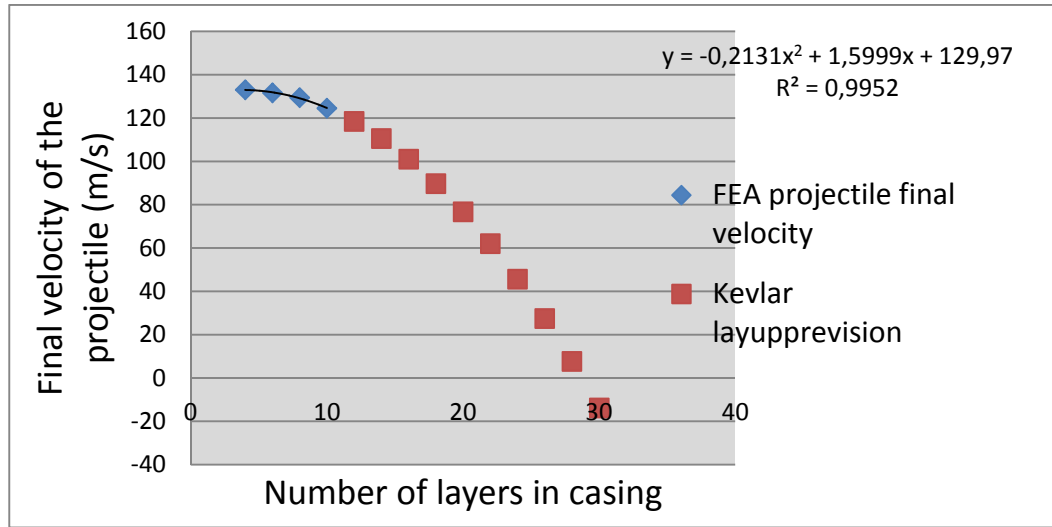


Figure 16: Velocity evolution predictions of the fan blade for different configuration of the casing

The interpolation/extrapolation performed in Excel using the FEA results yields the following function to predict the number of Kevlar layers needed to stop the blade:

$$f(X) = -0.2131X^2 + 1.5999X + 129.97 \quad (3)$$

In its turn, this analytic function is used to compute some predictions of the residual velocity in terms of number of fabric plies. The results are shown in red in Figure . According to this preliminary analysis one could conclude that approximately 30 layers of fabric are needed to stop the projectile from completely perforating the engine casing. However, care should be taken with this value because by the time being, we have insufficient data to make an accurate prediction. However, in order to further support this conclusion we have run a very large analysis with a 30 layers of fabric configuration of the containment vessel. 30 layers were chosen specifically because it is roughly the number of layers needed to stop the projectile. This analysis crashed however before completion but the goal was to observe the evolution of the impactor velocity during the first increments of the analysis and to compare it with the evolution obtained for the blade while working with 25-layers of full metallic casing which is able to stop the projectile. The results are presented in Figure .

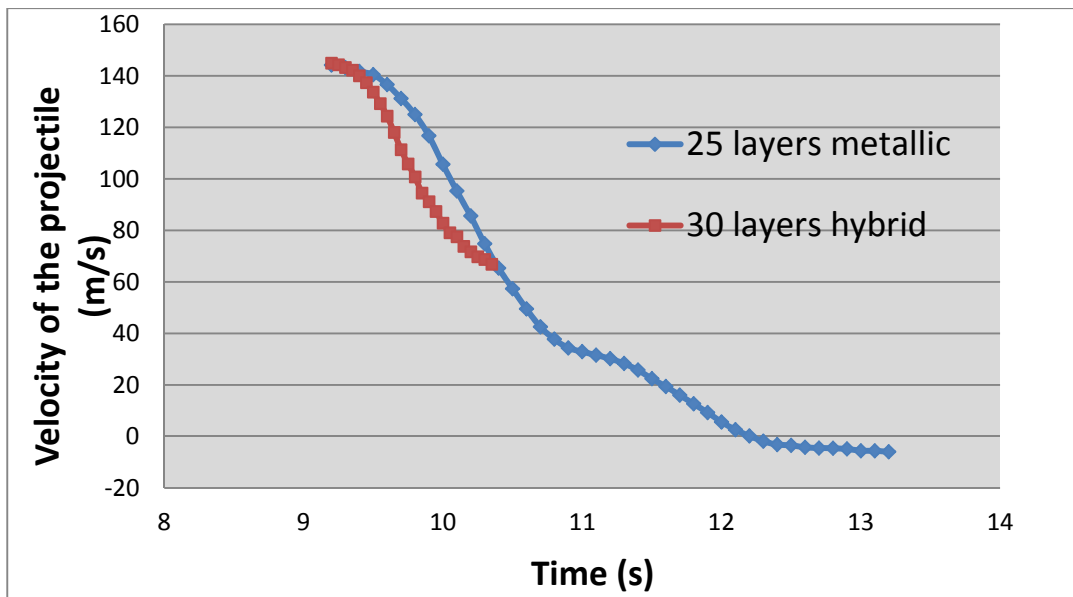


Figure 17: Comparison of the blade velocity evolution for the 25-layer metallic casing and the 30-layer hybrid casing

We can observe from figure 17 that the evolution of the two velocities is roughly the same at the beginning of the analysis time. Obviously further testing is still needed in order to arrive at clear conclusion.

## CONCLUSION

Composite or hybrid containment fan cases are in practice made from multiple layers of high performance fabrics to defeat the specific types of threats they are exposed to. Hence, as a result, a major part of the fabric target energy absorption stems from the interaction of individual layers with each other in the pack. To study such interaction existing in a real fan case, the shell crossover model is used to simulate the ballistic impact experiments on multi-ply Kevlar® 129 targets.

Numerical tests of a projectile impacting on a fabric plate were conducted and the influence of the number of plies on the final impact velocity has been studied. Also we studied the influence of various other material parameters that were input in the VUMAT to assess their influence over the results. Predicting how many plies were needed to stop the projectile based on partial simulation was a key objective of that section. It was found out that for a multilayered dry fabric flat plate it is indeed possible to predict the number of plies needed to prevent penetration and this prediction has been verified with numerical testing. In an attempt to extend the developed methodology to the design of an engine lightweight fanblade containment structure, curved soft wall structure is used and the underlying physics is seen to behave differently as in the case of flat structure since beyond ten layers of Kevlar dry fabric the analysis process blow up, indicating that the physics is not well captured. Hence more work is still going on in order to improve our material model.

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